

DETAIL EXPERIMENTAL TESTING OF UNMANNED AERIAL VEHICLES  
ENGINE PERFORMANCE

MOGANARAJ MURUGIAH

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## **ABSTRACT**

This project is about detail experimental testing of Unmanned Aerial Vehicles (UAV) engine performance. However, there is no proper selection of test bed available for the performance evaluation, testing and analysis of the UAV propulsion system. This project has two major objectives which are to design and fabricate a test bed for the UAV propulsion system and to conduct detail performance experimentations of the UAV propulsion system run at various speed. In this study, test bed model is designed to test the nitro engine Unmanned Aerial Vehicle (UAV) which is model of Thunder Tiger Pro36 Engine Series of aircraft performance. In addition, six performance parameters are recorded for testing of the engine performance, which are Thrust, shaft brake power, available power, propulsive efficiency, specific fuel consumption and thrust coefficient. Furthermore, the method used in this project is to identify the unknown variables in parameters by using some sensors. The results show that the fabricated test bed can be used to study the engine performance. Specifically, performance parameters are directly proportional to the engine speed. These results show that the performance parameters are increasing along with the speed. In conclusion, the fabricated test bed can be used for the testing of engine performance analysis. Outcomes of this experiment can be successful by using the test bed because it helps to reduce the cost and time for UAV propulsion performances testing.

## ABSTRAK

Projek ini adalah menjalankan eksperimen untuk mengkaji dan menganalisis ujian prestasi enjin untuk Pesawat Udara Tanpa Pemandu (PUTP). Walaubagaimanapun, pilihan janakuasa tidak dilaksanakan sepenuhnya dari segi operasi dan prestasi enjin. Projek ini mempunyai dua objektif utama iaitu mencadangkan reka bentuk analisis terperinci dan ujian prestasi Pesawat Udara Tanpa Pemandu (PUTP) sistem dorongan. Dalam kajian ini, model ujian katil diadakan bertujuan untuk menguji enjin nitro iaitu model Thunder Tiger Pro36 Enjin Pesawat dimana enam parameter prestasi telah dikaji seperti Teras, kuasa brek aci, kuasa yang ada, kecekapan pendorongan, penggunaan bahan api brek dan pekali teras. Tambahan pula, kaedah yang digunakan dalam projek ini adalah untuk mengenal pasti pembolehubah yang tidak diketahui dalam parameter dengan menggunakan beberapa sensor. Keputusan menunjukkan bahawa ujian katil direka boleh digunakan untuk mengkaji prestasi enjin. Kesimpulannya, ujian katil boleh digunakan untuk ujian analisis prestasi enjin. Hasil eksperimen ini boleh berjaya dengan menggunakan ujian katil kerana ia membantu untuk mengurangkan kos dan masa untuk ujian prestasi Pesawat Udara Tanpa Pemandu (PUTP) sistem dorongan.

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**LIST OF ABBREVIATION**

UAV	Unmanned Aerial Vehicle
RC	Radio Controlled
RPM	Revolution Per Minute
BSFC	Brake Specific Fuel Consumption
WW1	World War One
USN	US Navy
dL	Differential lift
dD	Differential drag
PIC	Programmable Interface Controller
FYP	Final Year Project
CAD	Computer-aided Design

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 PROJECT BACKGROUND**

The term UAV is an abbreviation of Unmanned Aerial vehicle, meaning aerial vehicles which operate without a human pilot. UAVs can be remote controlled aircraft which is flown by a pilot at a ground control station or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems. UAVs are commonly used in both the military and police forces in situations where the risk of sending a human piloted aircraft is unacceptable, or the situation makes using a manned aircraft impractical.

Advanced UAVs used radio technology for guidance, allowing them to fly missions and return. They were constantly controlled by a human pilot, and were not capable of flying themselves. This made them much like today's RC model airplanes which many people fly as a hobby.

After the invention of the integrated circuit, engineers were able to build sophisticated UAVs, using electronic autopilots. It was at this stage of development that UAVs became widely used in military applications. UAVs could be deployed, fly themselves to a target location, and either attack the location with weapons, or survey it with cameras and other sensor equipment.

Modern UAVs are controlled with both autopilots, and human controllers in ground stations. This allows them to fly long, uneventful flights under their own control, and fly under the command of a human pilot during complicated phases of the mission.

Currently, UAVs have found many uses in police, military and in some cases in civil application. UAVs are often used in Aerial Reconnaissance to get aerial video of a remote location, especially where there would be unacceptable risk to the pilot of a manned aircraft. UAVs can be equipped with high resolution still, video, and even infrared cameras. The information obtained by the UAV can be streamed back to the control center in real time.

In many cases, scientific research necessitates obtaining data from hazardous or remote locations. A good example is hurricane research, which often involves sending a large manned aircraft into the center of the storm to obtain meteorological data. A UAV can be used to obtain this data, with no risk to a human pilot.

UAVs can be used to carry and deliver a variety of payloads in the logistics and transportation field. Helicopter type UAVs are well suited to this purpose, because payloads can be suspended from the bottom of the airframe, with little aerodynamic penalty.

The importance of this study is to obtain the engine performance parameters such as force, available power, shaft brake power, propulsive efficiency and break specific fuel consumption from the testing and to suggest suitable powerplant.

The method that has been chosen for this project is by doing experiment to predict the engine performance parameters. This is because by using this method the measurement of engine performance parameters will be more accurate.

## **1.2 PROBLEM STATEMENT**

In this technology era, the UAV propulsion systems are getting popular day by day. Thus, performing various operations on the performances of engine can be difficult since the proper test bed cannot be fully deployed and very limited on the selection. In developing new test bed, many criteria need to be taken into considerations. The criteria that must be taking care are the external design, conceptual design, and preliminary design and detail design.

In this study, the problem that needs to be handled is lack of test bed for performance evaluation, testing, and analysis for UAV propulsion system. There is no proper selection can be made for the test bed in designing new test bed. It is hard to get operational reliable system of UAV propulsion.

## **1.3 PROJECT OBJECTIVES**

For this project, there are two objectives to be achieved as listed below:

- To design and fabricate the test bed for UAV propulsion system experimentations.
- To conduct detail performance experimentations of the UAV propulsion system run at various speed.

## **1.4 PROJECT SCOPE**

The scope for this project are listed as follows:

- Parameters of performance testings. Six parameters are involved which are Thrust, brake power, available power, propulsive efficiency, specific fuel consumptions and thrust coefficient.
- Design PIC microcontroller to control the engine's throttle which increases/decreases rpm of the engine.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

The purpose of this chapter is to revise all the past research, journal, information or study about the UAV, parameters of performance and all others related topic to this project where it will discuss the importance of counter measure and comparison among others research so that it will be used as a guidance in this research.

#### **2.2 HISTORY OF UNMANNED AERIAL VEHICLE (UAV)**

Based on GlobalSecurity.org (2008), the history of UAV has already begun as early as before the United States of America enter the World War 1(WW1). Before the WW1, a seaplane that could operate without a pilot onboard is already developed by the US Navy (USN).

The USN has developed and used small plywood UAV in the Pacific for attacking heavily the defended targets. After experiencing heavy losses of aircraft and aircrews by the Army Air Corps, the Aphrodite Projects was introduced. This project uses the old B-17 aircraft loaded with explosive and driven by a pilot. After that, the pilot usage was replaced with radio control of the unmanned aircraft and was use to

send the B-17 to crash into a target. Later on, after WWII, the B-17 were used for testing's the atom bomb in the South Pacific.

In 1964, the Buffalo Hunter which is the US Air Force drone reconnaissance program was under full developed. This drone is use in the Vietnam War as a preprogrammed flight over enemy held territory. Later in 1980, the Pioneer UAV system was introduced where it was used in the Operations Desert Storm which will provide outstanding intelligence and fire support information to the base. While in 2004 due to Iraq War, over 450 UAV was used in the war where it is reported about four teams of 22 soldiers to operate the UAVs in each brigade and until this days, the UAV systems and design is currently ongoing of development process as the military power is being important subjects to every country.

## **2.3 UAV PROPULSION SYSTEM**

There are different views about the precise definition of UAVs (Newcome, 2004). For the purpose of this study, the definition provided by ASTM International was adopted. UAVs are here defined as an airplane, airship, powered lift, or rotorcraft that operates with the pilot in command off-board, for purposes other than sport or recreation (ASTM, 2005). The UAVs are designed to be recovered and reused (ASTM, 2005).

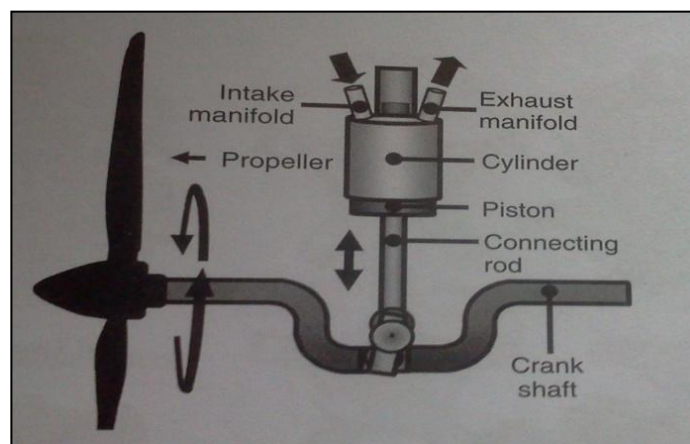
Radio controlled flight, usually referred to as RC, was largely developed by people with interests in both flying and amateur radio, like two early pioneers named Clinton DeSoto and Ross Hull, who flew gliders in the first public exhibition of RC flight (Raine et. all, 2002). He also mention about 1933 the first gasoline powered engines were developed for model airplanes. Although this made the model more realistic it also created the problem of preventing model with its expensive engine simply flying off over the horizon. It was Clinton DeSoto who first envisaged radio as the solution to this problem. Two other names must be mentioned in conjunction with the origins of RC whose is the twin brothers Bill and Walter Good. Walter had an enormous passion for model airplanes while Bill understood radio transmission, and

together in 1937 they built the first RC model plane. That first plane was given the name “Guff,” had an 8-foot wingspan, and weighed 8.5 lbs (Raine et. all, 2002).

In the area of propulsion, the main challenges facing UAV designers are related to the type of engine to employ. The main area of concern for small piston engines (under 50 hp) is reliability and maturity. The trend today is moving towards engines which have obtained certification and are of a high level of maturity. Improvements in UAV propulsion systems are very much dependent on improvements in engines developed for manned aircraft in general aviation, and turbofan / turboprop engines for larger aircraft. The improvements in piston engines are improved power/thrust to weight ratio, lower SFC and noise reduction.

There are several types of engine are used to drive propellers. These engines can be categorized into two major groupings which are internal combustion engines and gas turbine engines (Ward, 1966). Internal combustion engines also known as piston aerodynamic engines. The types of internal combustion piston engines are rotary engines, reciprocating engines, and supercharged reciprocating engines (Ward, 1966). But for this study, the focus only on reciprocating engines.

The engine types commonly used to propel UAVs are four-cycle and two-cycle reciprocating internal combustion engines, rotary engines, and increasingly, electric motors. In some cases, gas turbines are used in UAVs (Fahlstrom & Gleason, 1998).



**Figure 2.1:** Reciprocating engine

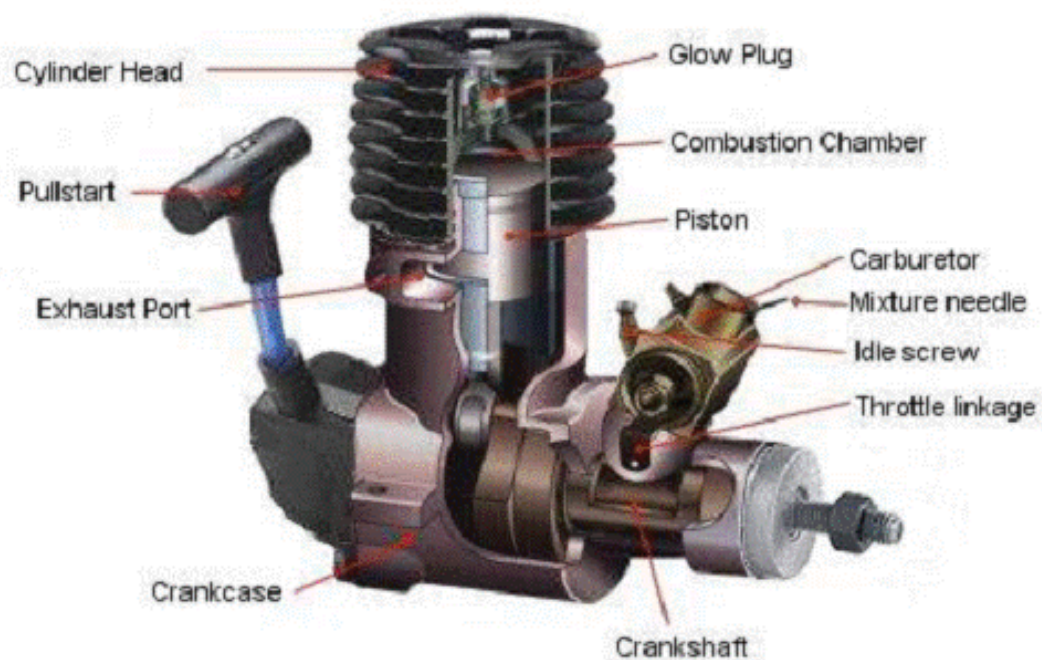
Source: Ward, 1966



There are two main propulsion systems used by RC models today which is the internal combustion system (nitro engines) and the electric motors. Combustion engines energy source has so far a higher energy/weight ratio than the batteries used to power the electrics. However, the combustion engines are usually noisier and more prone to oil spillage than the electric motors. There are two types of glow engines which is four-stroke and two-stroke. Two-stroke engines are the most used, mainly because they are simple made, light, easy to operate, easy to maintain, and are usually inexpensive. Two-stroke engines operate at a high RPM and therefore can be quite noisy without a good silencer. As state by (Bird, 2005), when talk about the size of a model airplane, it will usually refer to the size of engine needed to power it (measured in cubic inches). Typically models will be described as a size 20 (which needs a 0.20 HP to 0.36 HP engine), 40 (0.40 HP to 0.53 HP) or 60 (0.60 HP to 0.75 HP). These sizes refer to the capacity in cubic inches, such as, 0.36 cu in, of the most popular 2-stroke glow engines in use and will be adjusted if you change to a different type of engine.

The nitro engine was used in this project was the Max-46LA OS engine. As state by (Hobbico, 2000), the engine have been developed to meet the requirements of beginners and sport flyers which is modern design and having a separate needle-valve unit mounted at rear, where manual adjustment is safely remote from the rotating propeller, they offer the advantages of reliability and easy handling, at lower cost.

Nevertheless, the four-stroke engines also enjoy some popularity, mainly because they produce a lower, more scale-like sound and consume less fuel. They have lower power/ weight ratio and lower RPM, but provide more torque (use larger propellers) than theirs two-stroke counter-parts. However, since the four-stroke engines require high precision engineering and more parts to manufacture, they are usually more expensive. They also need more maintenance and adjustment than the two-stroke, yet they are not too difficult to operate and maintain.



**Figure 2.2:** Glow engine description

Source: Hobbico, 2000

The glow engine consists of:

1. Glow plug is a type of small internal combustion engine typically used in model aircraft, model cars and similar applications.
2. Combustion chamber is the part of an engine in which fuel is burned.
3. Piston is a component of reciprocating engines.
4. Carburator is a device that blends air and fuel for an internal combustion engine.
5. Idle screw on carburator is used to control the amount of air that is allowed into the carburator continuously, keeping the engine alive when the vehicle is in neutral.
6. Throttle linkage is the mechanism by which the flow of a fluid is managed by constriction or obstruction. An engine's power can be increased or decreased by the restriction of inlet gases.
7. Crankshafts transform the movements of the piston into rotational motion.
8. Crankcase is the housing for the crankshaft.
9. Exhaust Port is an outlet for dissipating the excess heat produced by the large energy reactors.
10. Cylinder head is a crucial part of all combustion engines and cylinder head cracking can result in catastrophic damage to the engine.

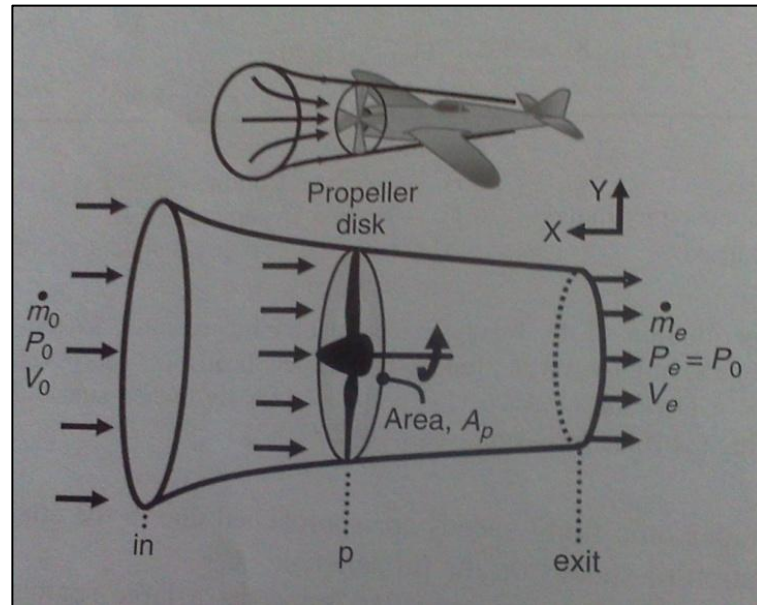
## 2.4 PERFORMANCE PARAMETERS

The parameters of this study are to measure the engine performance such as Available Power, Shaft Brake Power, Brake Specific Fuel Consumption, Propulsive Efficiency, Thrust, and Thrust Coefficient. There is only one type of engine that will be used in this study which is 2-stroke engine. The throttle control of the engine will be used to simulate the engine operating range from idle speed condition until achievable the maximum speed.

### 2.4.1 Thrust

The forces acting on the airfoil-shaped cross section of a propeller blade are complicated to determine analytically. At first glance, a seemingly simple method of calculating the thrust produced by a propeller blade would be to sum the forces for a small differential radial element ( $dr$ ) along the length of the blade. It is possible to determine the differential lift ( $dL$ ) and drag ( $dD$ ) from the lift and drag coefficients ( $C_L$  and  $C_D$ ) derived from the local airfoil shape and then integrate this equation (Ward, 1966).

However, an ideal approximation of thrust can be derived from the momentum equation by considering a control volume enclosing the airflow accelerated by the propeller (Figure 2.3). This analysis assume that the air flow steadily from a region in front of the propeller ( $P_o$ ,  $V_o$ ,  $\rho_o$ ) to the exit region behind it ( $P_e$ ,  $V_e$ ,  $\rho_e$ ). This method is generally known as the momentum theory (Ward, 1966).



**Figure 2.3:** Control volumes surrounding a propeller

Source: Ward, 1966

It is assumed that flow outside of the propeller stream tube does not experience any change in total pressure. Therefore the pressure terms everywhere are balanced, so the only force on the control volume is due to changes in longitudinal (x-direction) momentum fluxes across its boundaries. Propeller was known by modelers, as “props”, the sole purpose of this important and often overlooked piece of equipment is to pull (and sometimes push) the airplane through the air (Tressler, 2008). The suitable type and size of propeller is important to draw maximum power output from the Remote control engine. As the ideal propeller diameter, pitch and blade area vary according to the size, weight and type of model, final propeller selection will require in flight experimentation. The suggested propeller sizes are given in the table (Hobbico, 2000).

**Table 2.1:** The suggested propeller sizes for different engine ratings.

LA Series	Running-in	Trainer & Sport
40 LA	11×5	10×6-7, 10.5×6, 11×5-6
46LA	11×6	11×6-7
65LA	12×6	12×7-8, 13×6-8

There are several types of propellers in use on model airplanes. They include two, three, and four blade types. By far, the most popular propeller for a trainer plane is a two blade type made of wood or plastic (Tressler, 2008). Most used are plastic propellers. Propellers are sized using two numbers; diameter and blade pitch. A very common prop size for a 40 to 46 trainer engine is a 10-7. The first number is the diameter of the propeller in inches. The second is the blade pitch expressed as a number representing the theoretical distance the airplane travels forward for each revolution of the propeller.

In the example propeller, the 10-7 indicated a 10 inch propeller that moves the airplane forward 7 inches per revolution. Model engine propellers range in overall diameter from 5 inches up through and including. The main advantage of plastic over wood primarily is the increased durability of plastic. Chances are good to break a wood propeller more easily during initial flight training.

Most important thing while handling the propeller is never touch, or allow any object to come into contact with the rotating propeller and do not crouch over the engine when it is running (Hobbico, 2000). The rotating propeller will produce thrust as shown in Figure 2.3. The ideal thrust equation for piston aerodynamics engines as shown in Eq. (2.1).

$$F_N = \dot{m}_e V_e - \dot{m}_o V_o = \dot{m}(V_e - V_o) \quad (2.1)$$

Where,

$\dot{m}_e$  is mass flow rate at exit of propeller (kg/s).

$\dot{m}_o$  is mass flow rate at inlet of propeller (kg/s).

$V_o$  is air velocity at inlet of propeller (m/s).

$V_e$  is air velocity at exit of propeller (m/s).

For this study, assume that the force is equal to the spring constant times the distance the spring is elongated from its equilibrium position in meters. The force can be measure by the simple equation known as Hooke's Law as Eq. (2.2).

$$F = kX \quad (2.2)$$

Where,

k is the spring constant(N/m).

X is elongation of spring during parameters testing (m).

Hence, in order to measure the thrust exert by propeller while the engine start, the spring was placed on between the rear slider and spring's stand to measure the force by measure the elongation of the spring while force from the propeller pulls the slider toward. The value of force can be calculated because the spring constant can be measured.

#### **2.4.2 Available Power and Shaft Brake Power**

A propeller generates thrust by inducing a low pressure region in front of itself and a high pressure region behind itself ( $P > P_o$ ). (A detail kinematic model that describes all the aerodynamics forces involved is very complex and beyond the scope of this study.) The air pressure downstream of the propeller eventually returns to free stream conditions, but just behind the propeller the air velocity is greater than the free stream velocity ( $V_o$ ). This is because the propeller has done work on the airflow (Ward, 1966).

In actual piston aero engines the shaft brake power cannot be perfectly transmitted to the propeller as available power, because of losses associated with the compressibility of air. The available power is the rate that useful work is done. The equation of available power can be simplified as shown in Eq. (2.3).

$$\dot{W}_A = F_N V_o \quad (2.3)$$

Where,.

$F_N$  is the thrust of the engine (N).

$V_o$  is air velocity at inlet of propeller (kg/s).

The shaft brake power is simply equal to the power expended by the propeller and imparted to the fluid. This is simply the rate of change in the kinetic energy of the flow passing through it. The equation of shaft brake power can be simplified as shown in Eq. (2.4).

$$\dot{W}_B = \dot{m} \left[ \left( \frac{V_e^2}{2} - \frac{V_o^2}{2} \right) \right] \quad (2.4)$$

Where,

$\dot{m}$  is mass flow rate of air at propeller (kg/s).

$V_o$  is air velocity at inlet of propeller (m/s).

$V_e$  is air velocity at exit of propeller (m/s).

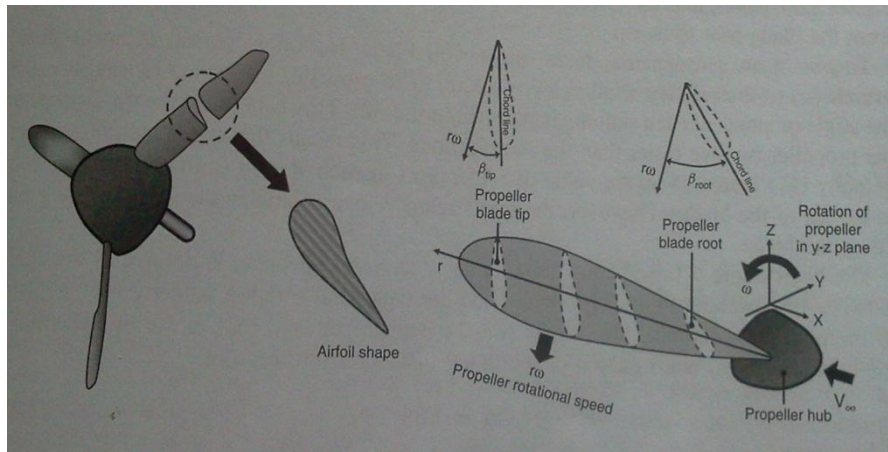
The unknown that needed to solve the equation is the speed of the air in front and rear the propeller. Hence, the anemometer is used to get the value of  $V_o$  and  $V_e$  in front and rear the propeller at specific engine speed so that the available and shaft brake power data can be obtain.

### 2.4.3 Propulsive Efficiency

Aircraft propellers generally consist of two to six propeller blades as discussed in previous section. The number of blades needed depends upon the power of the engine. More powerful engines require a greater number of blades to efficiently convert this power into thrust. Unlike marine propellers, all aircraft propeller blades are arranged radials perpendicular to the axis of rotation and consist of a set of airfoil-shaped cross section. The term station is used to define radial positions ( $r$ ) along a

propeller from root (or hub) to tip. At any station the blade cross section has an airfoil shaped, but this shape may vary in outline at different stations. A wing is fixed (with respect to the airplane) and only experiences the relative free-stream flow of the air. A propeller is not fixed because it rotates. Therefore a propeller experiences an oncoming flow of air that is the vector sum of the airplane's velocity (also called the free-stream velocity,  $V_o$ ) and the propeller rotational velocity (Ward, 1966).

As state by (Ward, 1966), Figure 2.4 illustrates the airfoil cross section of a propeller. Early propellers generally used airfoil cross sections that were similar to those used in wings. But as new higher speed aircraft were developed these airfoils proved to be inefficient. This is because the local velocity acting on specific propeller section is higher than the speed of the aircraft. This can cause flow separation or the formation of shock waves in the propeller airstream. This phenomenon known as a compressibility burble causes thrust losses and additional drag.



**Figure 2.4:** Cross-Section of a propeller

Source: Ward, 1966

It is useful to define a propeller efficiency ( $\eta_{prop}$ ) that relates the fraction of shaft brake power delivered to the propeller and converted into propeller thrust power (available power) as shown in Eq. (2.5).

$$\eta_p = \frac{F_{N,prop} V_o}{\dot{W}_B} = \frac{\dot{W}_A}{\dot{W}_B} \quad (2.5)$$